Committee on Resources

Statement

Ocean conditions and Columbia River salmon
Testimony provided for the House Subcommittee on Power and Water
April 25, 2000
Pasco, Washington

By Nathan J. Mantua, Ph.D.
University of Washington
Joint Institute for the Study of the Atmosphere and Oceans/School of Marine Affairs Climate Impacts Group
Box 254235
Seattle, WA 98195-4235

Summary

Though scientists are not certain of all the factors controlling salmon marine survival in the Pacific Northwest, several ocean-climate events have been linked with fluctuations in Northwest salmon health and abundance. These include: El Niño/La Niña, the Pacific Decadal Oscillation, the Aleutian Low, and coastal upwelling. Each of these features of the climate system influences the character and quality of marine habitat experienced by Pacific salmon.

Cooler than average coastal ocean temperatures prevailed from the mid-1940's through 1976, while relatively warm conditions prevailed from 1925-to-1945 and again from 1977-to-1998. The decades-long climate cycles have been linked with the Pacific Decadal Oscillation, an especially long-lived El Niño-like feature of Pacific climate. In the past century, warm ocean temperature eras coincided with relatively poor ocean conditions for many Pacific Northwest salmon stocks, while cool ocean temperature eras coincided with relatively good ocean conditions for Northwest salmon.

Pacific climate changes beginning in late 1998 indicate that the post-1977 era of unusually warm coastal ocean temperatures may have ended. Coincident with the demise of the extreme 1997-98 (tropical) El Niño, ocean temperatures all along the Pacific coast of North America cooled to near or below average values, and this situation has generally persisted to date. Recent climate forecasts, largely based on expectations for continued but weakening (tropical) La Niña conditions, suggest that the cool coastal SSTs are likely to persist through at least the spring, and probably through the summer, of 2000. Beyond the coming summer, there are no strong indications that major changes in the ocean state should be expected. If the recent past is a useful guide to the future, one might surmise that there is a reasonably good chance that cool coastal ocean temperatures will persist for the next twenty to thirty years. On the other hand, there has been no demonstrated skill in North Pacific climate predictions beyond about one year lead times. Thus, a lack of understanding for Pacific interdecadal climate changes bases 20-to-30 year forecasts more on faith than science. With a focus on the next 5-to-7 years, one may be much more confident in predicting that coastal ocean temperatures and coastal marine habitat quality will continue varying within and between seasons, as well as within and between years.

An expanded discussion of the impact of varying ocean conditions on Pacific salmon follows.

El Niño/La Niña

El Niño has received a lot of bad press for causing warm biologically unproductive conditions in the coastal waters of the Northeast Pacific Ocean. Especially intense El Niño events in 1982/83 and 1997/98 were connected with exceptionally warm coastal waters from Baja California to the Gulf of Alaska. Scientists have determined that El Niño plays an important role in North Pacific climate, but it is only one piece of a more complicated climate-ecology puzzle.

El Niño is Earth's dominant source of year-to-year climate variations. This phenomenon is understood to be a natural part of this planet's climate that spontaneously arises from interactions between Pacific Trade Winds and ocean surface temperatures and currents near the equator. It is important to keep in mind that the "essence" of El Niño is contained within the tropics, thousands of miles to the south of where any North Pacific salmon ever swims. However, swings between El Niño, and its cold counterpart La Niña, have consequences for climate around the world. Simply put, massive changes in the distribution of tropical rainfall, which are directly related to changing ocean temperatures in the tropical Pacific, influence atmospheric pressure patterns, winds and storm tracks thousands of miles away. These changes over the North Pacific and North America are especially strong in the months from October through March. During these months, El Niño influences the character of the dominant feature of North Pacific weather, the Aleutian Low pressure cell.

Aleutian Low

The Aleutian Low is a semi-permanent atmospheric pressure cell that settles over much of the North Pacific from late fall to spring. The exact position and intensity of the Aleutian Low varies greatly from week-to-week, year-to-year, and even decade-to-decade.

an El Niño period with an intense Aleutian Low: October 1997-March 1998	**a La Niña period with a weak Aleutian Low: October 1971-March 1972**

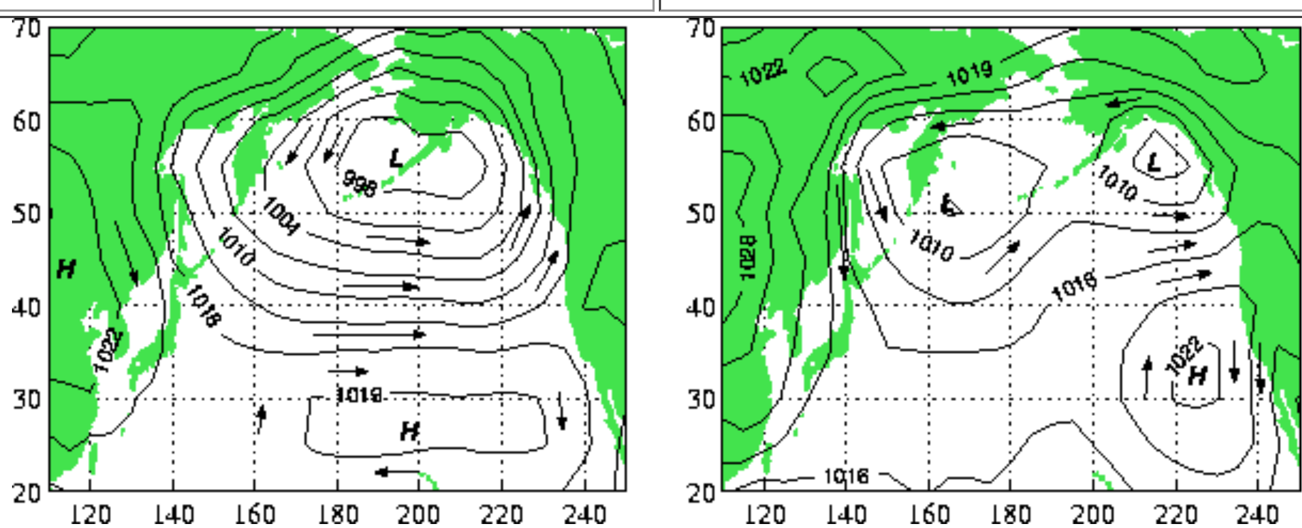

Figure 1: Observed winter/spring sea level pressure fields during strong and weak Aleutian Low periods. Arrows indicate the prevailing surface winds that are driven by these pressure patterns. An intense Aleutian Low can occur in any winter, but is

especially likely during a strong El Niño event. Likewise, a weak Aleutian Low can occur at any time, but is especially likely during a strong La Nina event.

An intense Aleutian Low favors northward winds along the Pacific coast, and causes relatively dry, mild winter and spring weather. In the left panel of Figure 1 is a map with contours for atmospheric sea level pressures from October 1997-March 1998, at the height of the 1997/98 El Niño. This was a period with an exceptionally intense Aleutian Low, which can be identified as the bulls-eye of low pressure values centered over the Aleutian Islands. Northern Hemisphere surface winds blow in a direction that almost parallels the contour lines but angled slightly toward lower pressures, counter-clockwise around the lows and clockwise around the highs. Of special significance to the Pacific Northwest's coastal ocean is the fact that relatively warm northward blowing near-shore winds caused by a strong Aleutian Low tend to drive surface waters onshore (to the right of the wind direction), piling up relatively warm nutrient poor water in the coastal zone.

On the other hand, periods with a relatively weak Aleutian Low favor onshore coastal winds that move surface currents to the south. In the right panel of Figure 1 is a contour map for sea level pressures from October 1971-March 1972, a La Niña period with a weak Aleutian Low. Notice that in this year there were two relatively weak low pressure centers in the North Pacific, one near the coast of Asia and the other in the Gulf of Alaska. Also note the strong high pressure cell located off the coast of Northern California. Periods with a weak Aleutian Low typically bring relatively wet and cool winters to the Pacific Northwest region. In weak circulation periods the coastal ocean surface waters are cooler, less stratified and richer in nutrients because onshore currents are relatively weak. Off the coast of Northern California the strong high pressure cell causes southward upwelling winds even in the winter months.

Pacific climate events in the past few years have followed an often observed pattern: the 1997/98 tropical El Niño favored an intense Aleutian Low, while the 1998-2000 La Niña has favored a relatively weak Aleutian Low. Additionally, El Niño sends coastal currents from the tropics that travel northward along the coast of North America. These also warm and stratify the near-shore coastal waters, reinforcing the wind-driven warming and stratification brought by the intense Aleutian Low. Likewise, La Niña produces coastal currents that cool and weaken the stratification in the surface waters, reinforcing the La Niña-influenced, wind-driven cooling. In both El Niño and La Niña, the Pacific Northwest's coastal ocean is affected by changes in the oceanic and atmospheric circulation that can be traced to the equatorial Pacific--a long-range double whammy.

The maps shown in Figure 2 highlight some of the dramatic year-to-year changes that El Niño and La Niña can bring to the west coast's ocean. In the left panel are observed sea surface temperatures in December 1997, near the peak of the last El Niño event. The contour lines and shading depict temperatures as deviations from the long term average. Actual temperature values are shown with the larger numbers. West coast sea temperatures were 3-to-5 degrees Fahrenheit above average in a thick layer of warm water that extended to depths of 50-to-100 meters below the surface. The wide belt of warm and sharply stratified surface waters had been present since the previous summer.

In May and June of 1998 the tropical El Niño was quickly replaced by La Niña conditions, a climatic switch that set the stage for a dramatic ocean cooling along the west coast of North America. Coastal ocean temperatures in December of 1998 (shown in the center panel) were actually a bit colder than the long term average, some 3 to 5 degrees Fahrenheit lower than those observed 12 months prior. An important factor behind this cooling was the prevalence of a weak Aleutian Low from October 1998 through April 1999. Throughout this period, North Pacific barometric sea level pressures often resembled those in the right panel of Figure 1. During December of 1999 (right panel of Figure 2) ocean temperatures were again mostly near to below the long-term average. This second year of cool coastal ocean temperatures is clearly related to a second fall and early winter with a weak Aleutian Low, which in turn has been influenced by the second consecutive year of tropical La Niña conditions.

December 1997	December 1998	December 1999
El Niño year	**La Niña year**	**La Niña year**

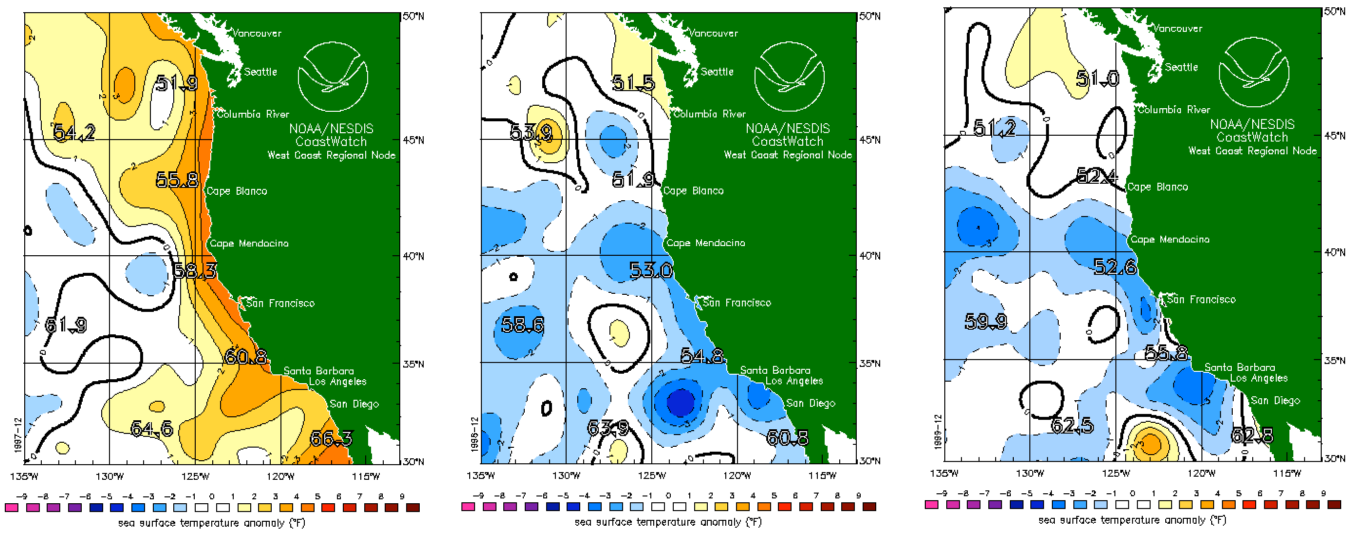

Figure 2: Coastal ocean temperature fields for December 1997, 1998 and 1999. The shading and contours show temperature deviations from the long term December average, while the large blocked numbers show the actual temperatures in degrees Fahrenheit. Note that coastal ocean temperatures in December of 1997 were 3 to 4 F above average, while temperatures in December 1998 and 1999 were generally near or cooler than average for most of the region shown. These maps were obtained from NOAA's Coast Watch web-site (url: *http://cwatchwc.ucsd.edu/elnino.html*).

Upwelling and Coastal Productivity

As the spring/summer upwelling season approaches, the coastal ocean is often primed for either rich or poor biological productivity. Clearly, the coastal ecosystem will be strongly influenced by the presence or lack of upwelling winds, but it will also depend upon the character of the preceding winter/spring Aleutian Low circulation and related ocean conditions. Following a weak Aleutian Low, cool and weakly stratified surface waters favor an especially productive food-web because upwelling winds are able to tap into the nutrient rich subsurface waters with little resistance. Conversely, following an intense Aleutian Low, warm and sharply stratified surface waters tend to have poor biological productivity even in the presence of strong upwelling winds. The warm stratified upper ocean effectively caps the nutrient rich waters at depth. Upwelling in a sharply stratified ocean simply recycles the same depleted water in the surface layer over and over again, never replenishing the nutrients that are quickly used up by phytoplankton.

Low phytoplankton production cascades through the marine food-web. Zooplankton and small fish that feed on plankton become scarce, resulting in low food production for salmon. For juvenile salmon, this low productivity may result in slow growth which can also make them more vulnerable to predation, leading to lower smolt survival rates. Also, during warm years many fish from subtropical waters, such as mackerel, migrate into coastal waters of the Pacific Northwest from the south. These fish may compete with young salmon for food, and in some cases even target juvenile salmon as prey.

Pacific Decadal Oscillation

Typically, individual El Niño or La Niña events play out over the course of 8 to 14 months. However, climate records kept over the past century document decades-long warm and cool eras in the Pacific Northwest's coastal ocean that are superimposed upon the year-to-year changes associated with El Niño and La Niña. Recent research points to a second important player in North Pacific climate, the recently named Pacific Decadal Oscillation, or PDO.

The PDO has been described as a long-lived El Niño-like pattern of Pacific climate variability. Extremes in the PDO pattern are marked by most of the same Pacific climate changes caused by El Niño and La Niña. Two main features distinguish the PDO from El Niño. First, typical PDO "events" are much longer-lived than a typical El Niño - in the past century major PDO regimes have persisted for 20-to-30 years. Second, evidence of the PDO is most visible in the North Pacific/North America sector, while secondary signatures exist in the tropics - the opposite is true for El Niño. In short, warm and cool eras of the PDO do most of the same things to Pacific climate that swings between El Niño and La Niña do, but the PDO does them for 20-to-30 years at a time.

The record of coastal sea temperatures shown in Figure 3 illustrates some of the impacts of PDO climate cycles. This data comes from the west coast of Vancouver Island near a lighthouse at Amphitrite Point . The record is presented in two ways: monthly deviations from the long term mean are shown with the thin line, and 5-year running averages are shown with the thick line. The month-to-month temperature fluctuations can be as large as a few degrees, while decade-to-decade variations are more typically about +/- 1 degree Fahrenheit. Temperature records from stations along most of the Pacific Coast show the same prolonged periods of above average temperatures in the early 1940's, then again from 1977-1998. Coastal temperatures were mostly lower than average from the mid-1940's through 1976. Since the fall of 1998, sea surface temperatures at Amphitrite Point have been near or below average in most every month to date.

Several independent studies find evidence for just two full PDO cycles in the past century: cool coastal ocean regimes for the PNW prevailed from about 1890-1924 and again from 1947-1976, while warm coastal ocean regimes dominated from 1925-1946 and from 1977 through 1998. Climate reconstructions based on tree-rings from the Pacific Northwest suggest that the PDO has been an important player in Pacific climate for at least the past few centuries, and that 20-to-30 year climate regimes are normal.

Coastal ocean temperatures at Amphitrite Point, British Columbia, Canada

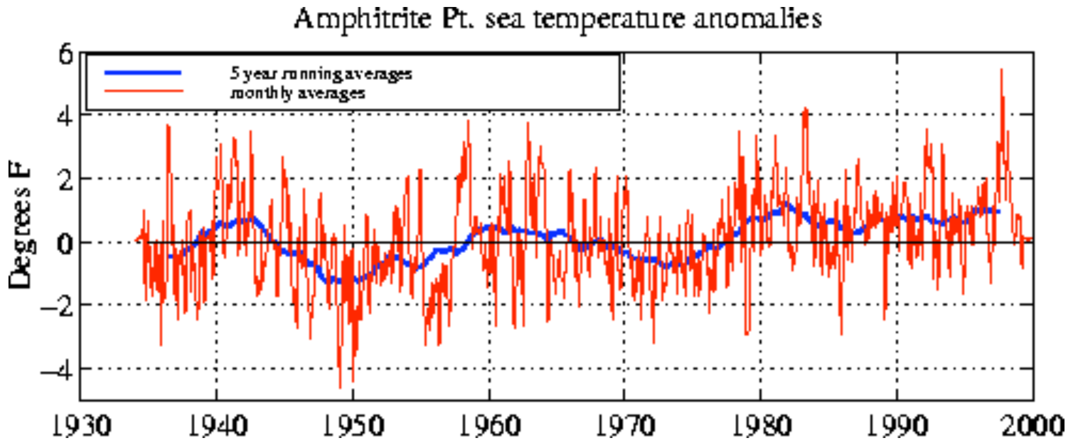

Figure 3: Record of coastal ocean temperatures from Amphitrite Point, on the west coast of Vancouver Island, British Columbia. Temperatures are plotted as deviations from the long-term average for the 1935-1999 period. These data were obtained from the Institute of Ocean Sciences web-site (url http//ios.bc.ca/)

Because causes for PDO climate cycles are not understood, it is now impossible to predict a PDO change before it occurs, or to accurately detect a PDO change while it occurs. The recent shifts to cooler ocean temperatures along the Pacific coast are one of the signals we expect to see with a shift from a warm to cool PDO regime. However, no one is certain if the recent cooling will fade away when the current La Niña leaves us--which is expected sometime in the summer or fall of 2000--or whether this coastal ocean cooling will stick around for the next 20 or 30 years as part of a cool PDO regime.

A number of recent studies find evidence for important decade-to-decade climate impacts on Pacific salmon. Essentially, the El Niño and La Niña impacts described above appear to play out over 20-to-30 year periods because of PDO climate cycles. An interesting finding is the that the biologically unproductive periods in the Pacific Northwest coincide with production booms in the Gulf of Alaska. Likewise, periods with especially high coastal ocean (and salmon) production in the northwest have coincided with low-production eras in Alaska. This north-south "inverse" production pattern is thought to arise in part because a warmer, more stratified ocean in the coastal waters of Alaska benefits phytoplankton and zooplankton production. The cool waters in the north are most always nutrient rich, but strong stratification is needed to keep phytoplankton near the surface where the energy from the high-latitude sunshine is limited. In the Pacific Northwest's coastal ocean, lack of nutrients from increased stratification is most often the limiting factor in phytoplankton production.

Ocean conditions and strategies for increasing Columbia River salmon runs in the next 5-to-7 years:

Given the growing body of evidence that ocean conditions play an important role in regulating salmon health and abundance, what management steps might be taken to improve Columbia River salmon populations in the next 5-to-7 years and beyond? It seems that climate insurance for Columbia River salmon would be provided by adopting management strategies aimed at restoring some of the characteristics possessed by healthy wild salmon populations. Although the mechanisms are not completely understood, wild salmon evolved behaviors that allowed them to persist and thrive under variable ocean conditions. Excessive harvest of individual stocks, the widespread development of salmon hatcheries in the Columbia River system, and habitat loss and degradation, have combined to greatly simplify the complex population structures and behaviors that salmon evolved over millennia. In short, management actions taken to restore some of the wild salmon characteristics that have been lost in the past century are likely to be the best routes for minimizing the negative impacts of poor ocean conditions, and may also prove beneficial during periods of especially good ocean conditions. There should be little doubt that the ocean environment will continue to vary between favorable and unfavorable conditions for Columbia River salmon at both year-to-year and decade-to-decade time scales.

For additional information on the Pacific Decadal Oscillation, visit the following url:
http://jisao.washington.edu/pdo

Nathan J. Mantua
University of Washington
JISAO/SMA Climate Impacts Group
Box 354235
Seattle, WA 98195-4235
Ph: 206-616-5347
Fax: 206-616-5775
Email: mantua@atmos.washington.edu

url: http://www.atmos.washington.edu/~mantua/pasco_apr27